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SEA SURFACE TEMPERATURE ANOMALIES IN THE NORTH PACIFIC OCEAN

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Abstract: Twenty eight years of sea surface temperature anomalies in the North Pacific Ocean were compared with a first - order autoregression process which is forced by atmospheric white noise. The results showed that this process can explain the variance spectrum of these anomalies for much of the mid-latitude regions.

Hasselmann (1976) has recently proposed a stochastic model of climate variability in which slow changes of climate were explained as the integral response of the climate to continuous random excitation by shorter time scale disturbances. Frankignoul and Hasselmann (1976) have applied the model to a simplified atmospheric and oceanic system. In this system, sea surface temperature (SST) changes are produced by uncorrelated white noise atmospheric forcing. This input is assumed to be balanced by negative linear feedback representing a variance spectrum of SST anomaly of the form:

$$E(\omega) = \frac{A}{\omega^2 + \lambda^2} \quad , \tag{1}$$

where ω is the radian frequency, λ is the linear feedback factor, and A is the constant (white) input spectrum. In this paper (1) is compared with measured SST anomalies to determine in which regions of the ocean the stochastic model is applicable. For comparison with real data, (1) must be expressed in terms of the spectrum that would be determined for a discrete time series of sampling interval, Δt. Following Wunsch (1972), (1) becomes:

$$E(\omega) = \sum_{m=-\infty}^{\infty} \frac{B}{(\omega - 2m\omega_n)^2 + \lambda^2} \quad , \tag{2}$$

where the Nyquist frequency is $\omega_n = \pi/\Delta t$, m is an integer, and B is a constant. With the aid of an extension of Cauchy's integral theorem, (2) can be expressed more simply as:

$$E(\omega) = \frac{n_1}{1 + \alpha^2 - 2\alpha\cos(\pi\omega/\omega_n)} \quad , \tag{3}$$

where $1 + \alpha^2 = 2\alpha \cosh(\pi\lambda/\omega_n)$,

and

$$n_1 = B\left[\frac{\alpha\pi \sinh(\pi\lambda/\omega_n)}{\lambda\, \omega_n}\right] .$$

Equation (3) is simply the spectrum of a discrete first - order autoregression process which is forced by white noise. (c.f. Jenkins and Watts, 1968) where α is the autocorrelation of the first lag and n_1 is the variance of the noise term.

The measured SST anomalies were obtained from NORPAX data of the mid-latitude North Pacific. The data is available for 28 $\frac{1}{2}$ years as monthly average temperatures for a five degree square grid. For each grid location a spectrum, $\hat{E}(\omega_j)$ was computed at discrete frequencies $\omega_j = j\Delta\omega$ where $\Delta\omega = \omega_n/32$ (corresponding to ten degrees of freedom) and $j = 0, 1, \ldots, 32$.

To verify the stochastic climate model for SST anomalies, it must be shown that (3) is an adequate model of $\hat{E}(\omega_j)$. This was done by finding the two free parameters in (3), α and n_1, for each grid location, by minimizing the deviation, ε , between $\hat{E}$ and E by a least squares fit, where ε was defined by:

$$\varepsilon = \sum_{j=0}^{32} \left[\ln \hat{E}(\omega_j) - \ln E(\omega_j)\right]^2 . \tag{4}$$

This least squares fit was also determined for two different extensions of (3) containing three free parameters. The first, $E_1(\omega)$, included an extra noise term, n_2 , such that:

$$E_1(\omega) = \frac{n_1}{1+\alpha^2-2\alpha\cos(\pi\omega/\omega_n)} + n_2 \ .$$

The second, $E_2(\omega)$, is the spectrum resulting from a second - order autoregression, (Jenkins and Watts, 1968):

$$E_2(\omega) = \frac{n_1}{1+\alpha^2+\beta^2-2\alpha(1-\beta)\cos(\pi\omega/\omega_n)-2\beta\cos(2\pi\omega/\omega_n)},$$

where β is the second - order regression coefficient. In all cases the free parameters were determined independently by minimizing ε in (4).

The accuracy of each model spectrum can be found by defining a critical ε , $\bar{\varepsilon}$, such that the model is statistically valid within 95 % confidence limits for $\varepsilon < \bar{\varepsilon}$. Alternatively, one can first make the assumption that the model of $E_2(\omega)$ is valid everywhere. Then the value of the parameter β can be tested to determine if it is significantly different from zero. When it can not be distinguished from zero, then $E_2(\omega)$ reduces to $E(\omega)$, and the two parameter model may be considered valid (if the deviation, ε , is within approximately defined limits). If β is significantly different from zero, then the two parameter model must be rejected.

Two tests for the significance of β (c.f. Jenkins and Watts, 1968) were used. The results of the tests are shown in Figure 1. The cross-hatched regions indicate that both tests showed that β was zero. The diagonal regions indicate that only one test showed that β was zero. The open areas with a dot indicate five degree squares in which β was statistically significant.

Thus the two parameter model can be regarded as valid in the cross-hatched regions but not in the dotted regions. The dotted regions correspond to known areas of strong oceanographic processes such as the artic and subtropic convergences and the eastern Pacific upwelling areas. In these regions the oceanographic processes are apparently at least as important as the atmospheric forcing as the cause of SST variability. In the cross-hatched areas, where the two parameter model is valid, the oceanographic processes are less important and SST anomalies can be explained statistically by white noise atmospheric forcing.

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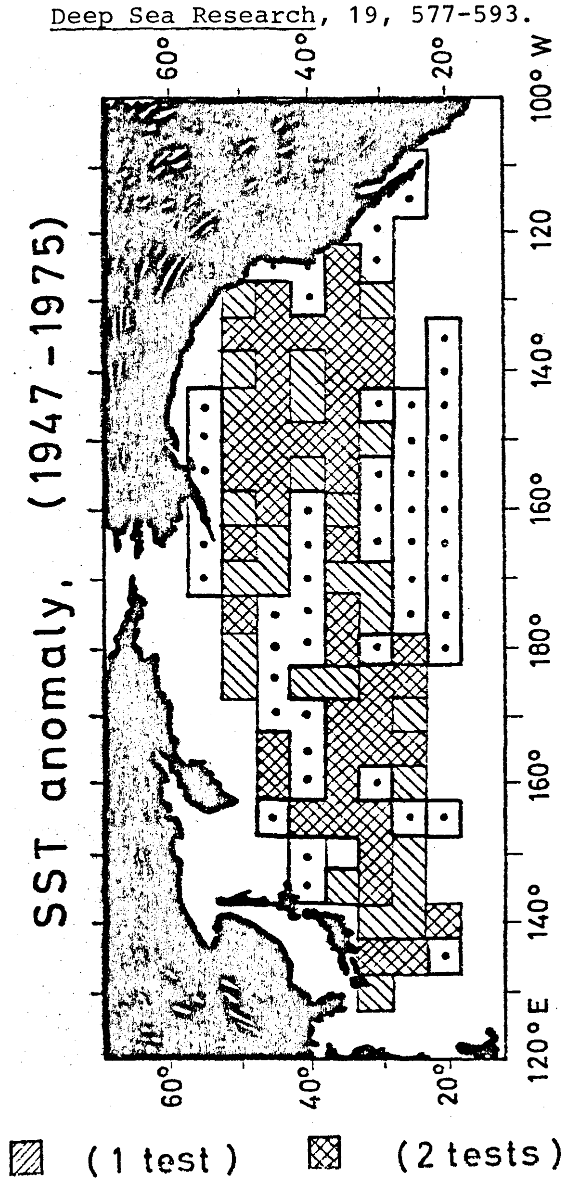

Figure 1: Regions of the North Pacific where SST anomalies can be described by first-order autoregression processes.